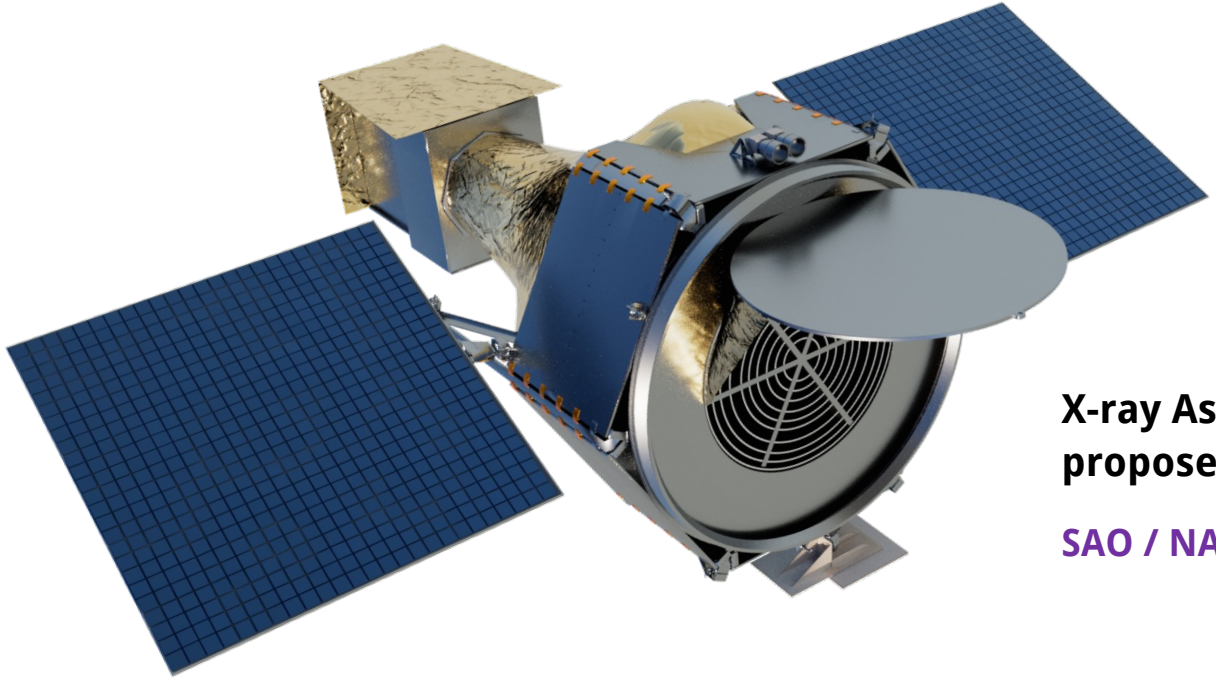
Line Emission Mapper

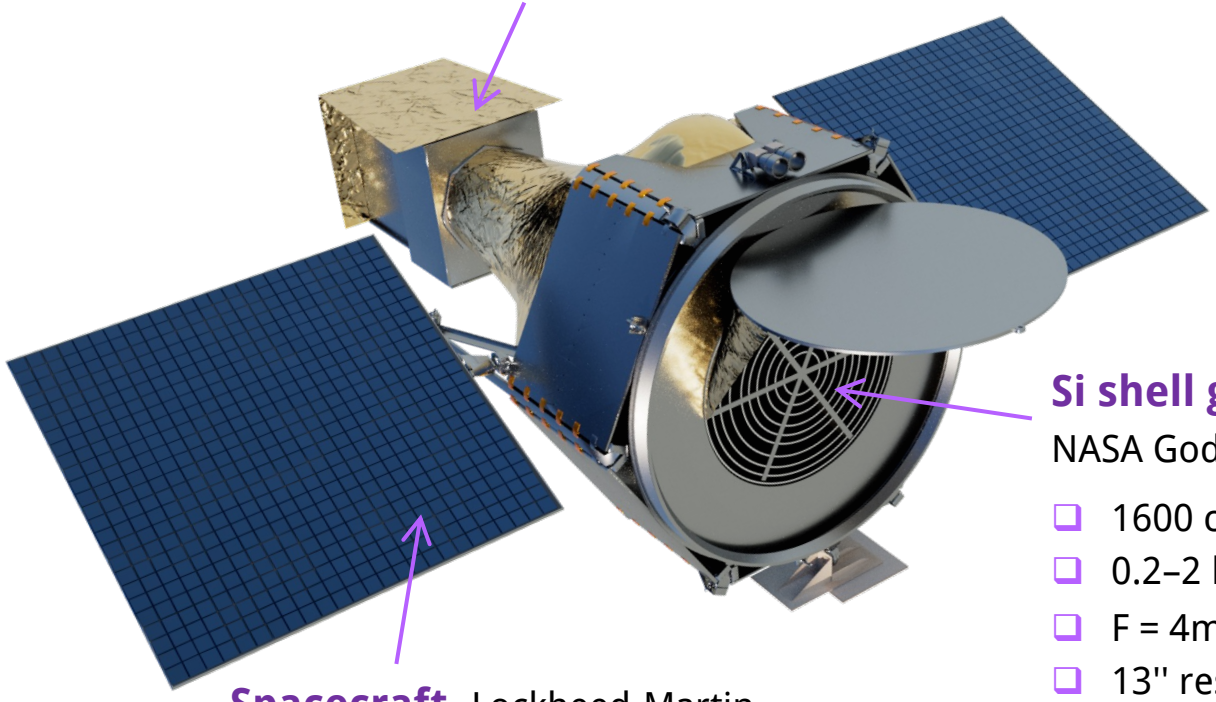


X-ray Astrophysics Probe concept proposed to NASA, November 2023

SAO / NASA GSFC / Lockheed-Martin

TES calorimeter array, NASA Goddard (building upon Athena XIFU)

- 30'×30' field of view, 118×118 array of 15" pixels (290μm pitch)
- 2 eV resolution; 1 eV in the 5'×5' central region
- Cooled to 40 mK (coolers by Lockheed-Martin, Goddard)



Si shell grazing-incidence mirror

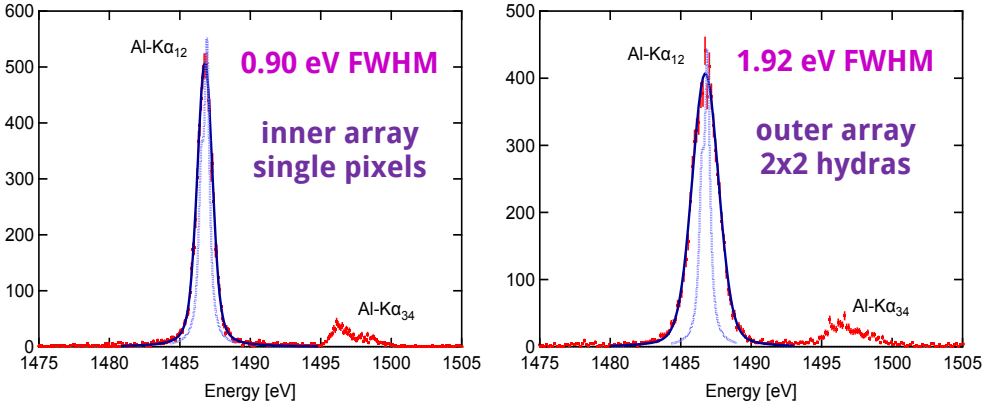
NASA Goddard (Will Zhang)

- 1600 cm^2 effective at E=0.5 keV
- 0.2–2 keV band
- F = 4m
- 13'' resolution (HPD; incl. pixelization)

Spacecraft, Lockheed-Martin

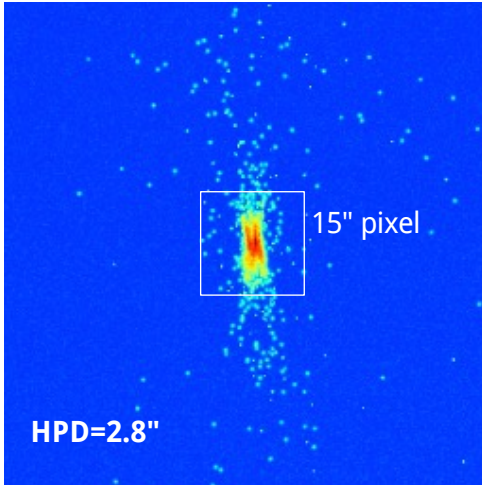
- Sun-Earth L1 orbit (can look at Earth)
- minimum 5 yr lifetime

Status of technology



Prototype detector energy resolution results

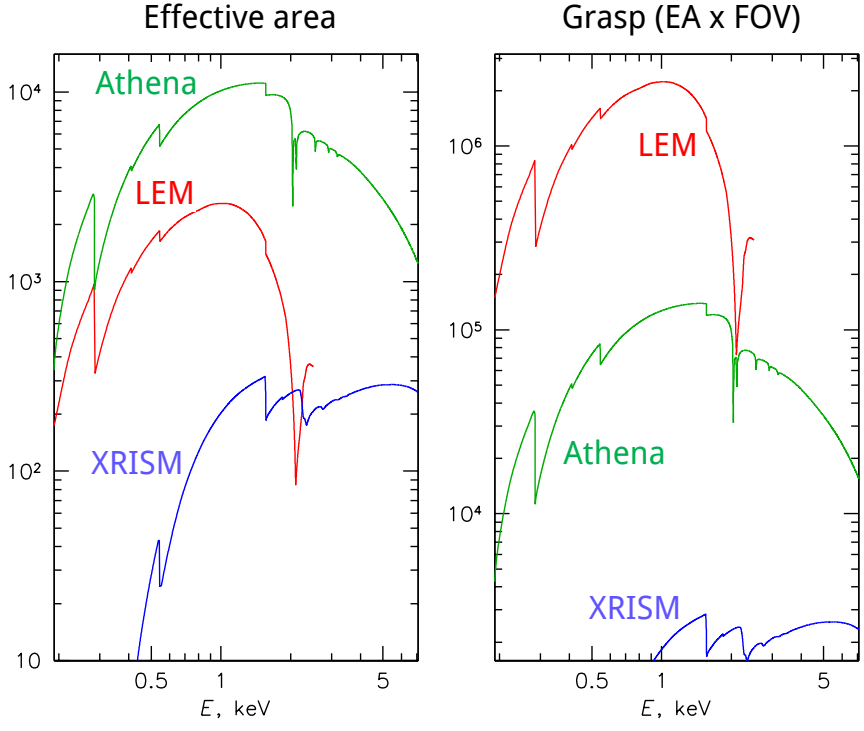
- single pixels (as Athena XIFU, etc.) in the inner 5'x5' region
- rest of detector: "hydra" pixels – 4 absorbers (15" pixels) connected to 1 TES – reduces number of readouts
- **already meets LEM requirements**



Angular resolution results, mirror subset (5 shell pairs)

- LEM mirror is similar to STAR-X
- **exceeds LEM requirements**

LEM vs current and future imaging spectrometers



	LEM	XRISM Resolve	ATHENA XIFU	HUBS
Energy band, keV	0.2–2	0.4–12	0.2–12	0.2–2
Effective area, cm^2 0.5 keV	1600	50	6000	500
Effective area, cm^2 6 keV	0	300	2000	0
Field of view	30'	3'	4'	60'
Grasp, 10^4 cm^2 $arcmin^2$	140	0.05	8	180
Angular resolution	15''	75''	5''	60''
Spectral resolution (FWHM)	1 eV central 5x5' 2 eV rest of FOV	5 eV	3 eV	2 eV
Detector size (equiv. pixels)	118 x 118	6 x 6	40 x 40	60 x 60

Science-driven architecture

Two broad frontiers of X-ray astrophysics:

- **the energetic Universe**
  - measure Doppler shifts of E=6 keV Fe line
    - needs a large focal length (small grazing angles) = small FOV for a microcalorimeter of a feasible size

- **galaxy evolution**
  - map extended sources whose signal is a forest of E~1 keV lines
    - use a short (fast) telescope = **large FOV**
    - trade high-energy sensitivity for **better energy resolution** using a microcalorimeter optimized for **narrower band**

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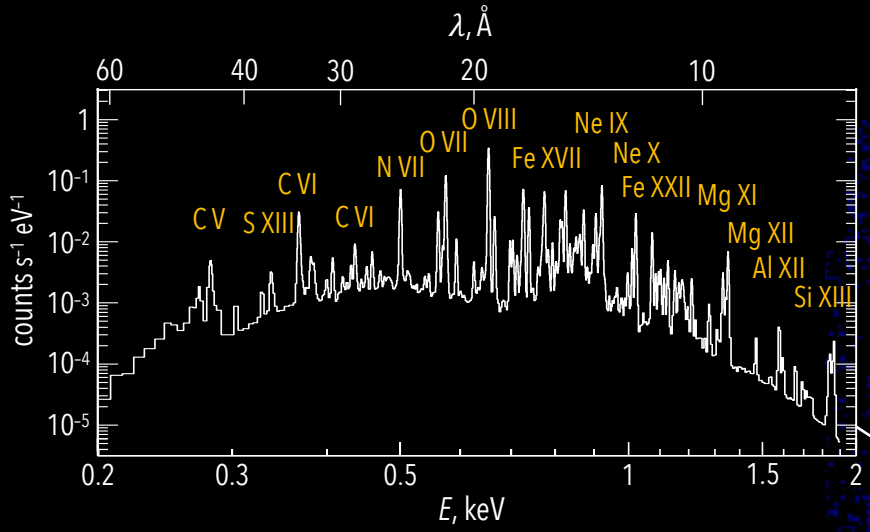
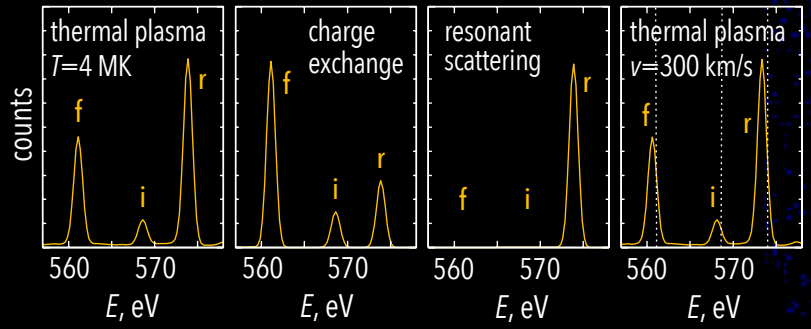
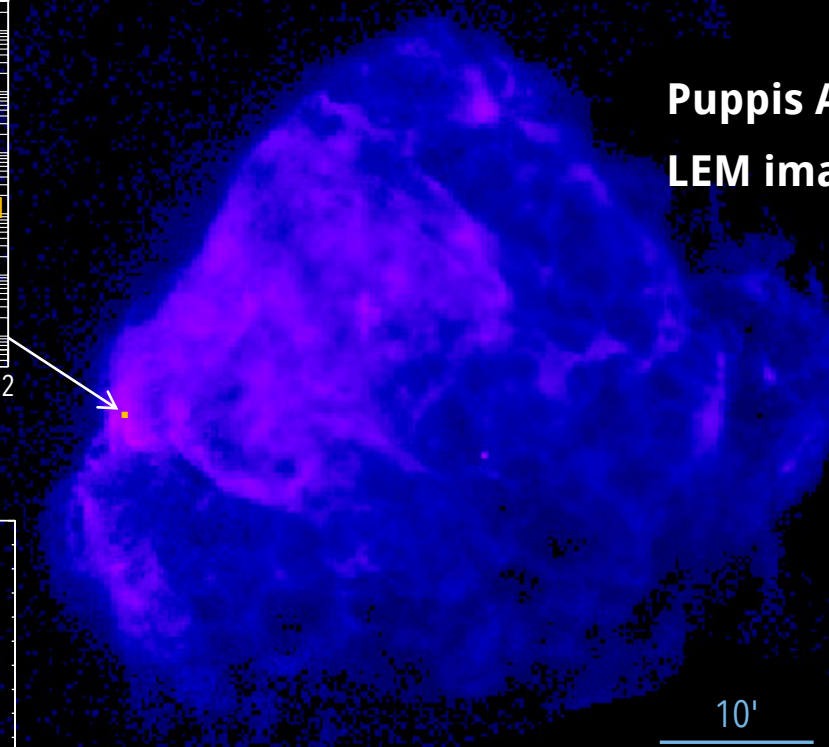
LEM data cube

- Image for every 1-2 eV spectral interval
- 1-2 eV resolution spectrum for every 15” image pixel



Plasma diagnostics with O VII triplet



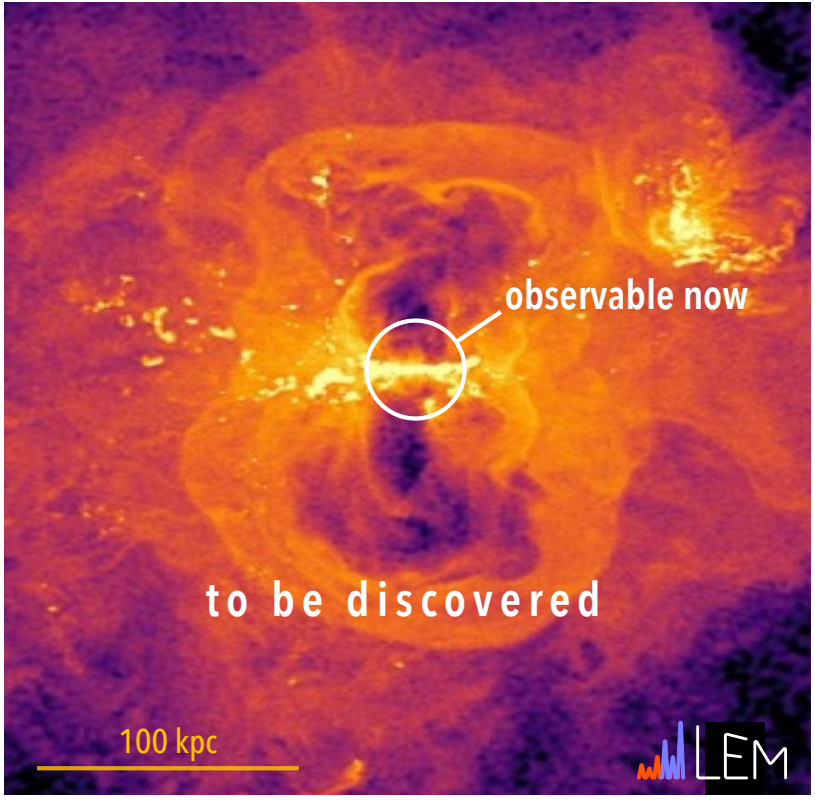


Puppis A SNR

LEM image

LEM science – Cosmic Ecosystems

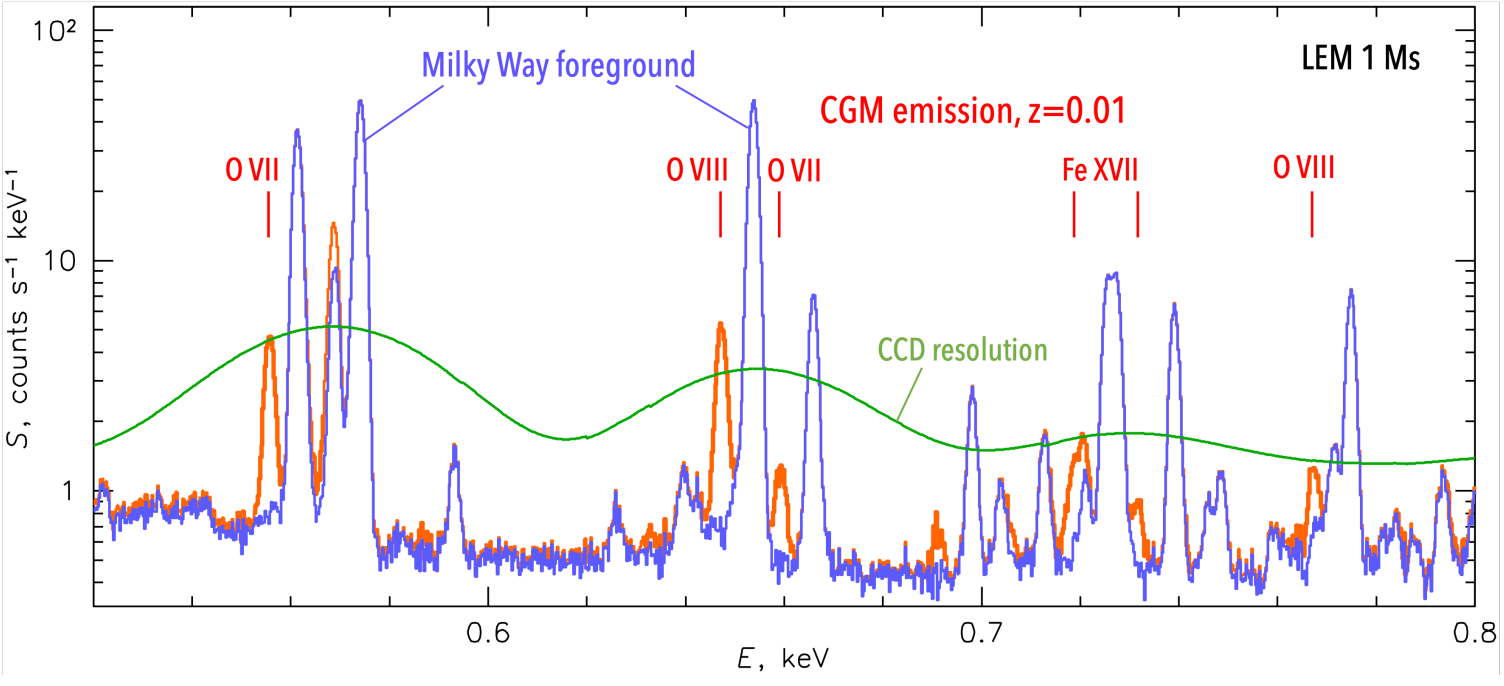
- Map extended gas halos around galaxies – the Circumgalactic Medium (CGM) – to determine the physical drivers of galaxy evolution
  - including CGM halo of our own Milky Way
- Detect and map metals in the Cosmic Web – to probe cosmological history of galactic feedback
- Map star-forming regions, superbubbles (including the Local Hot Bubble), SNRs of all ages, Fermi/eROSITA Bubbles, Galactic Center chimneys – the Milky Way ecosystem



Simulated Milky Way mass galaxy in X-rays

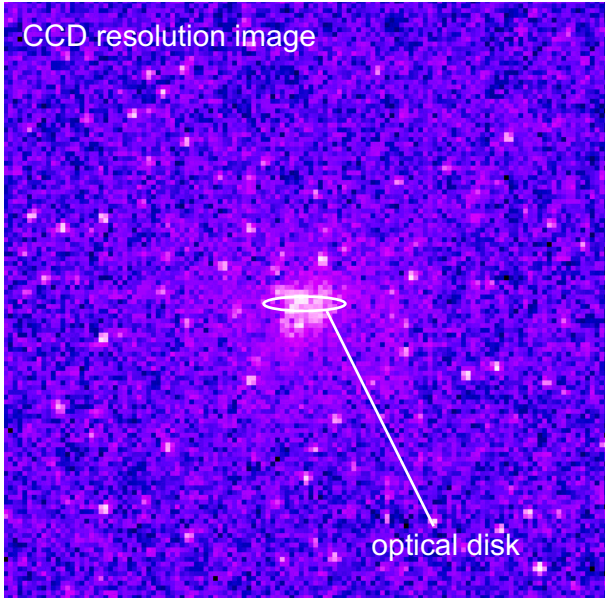
How to detect emission from galactic halos?

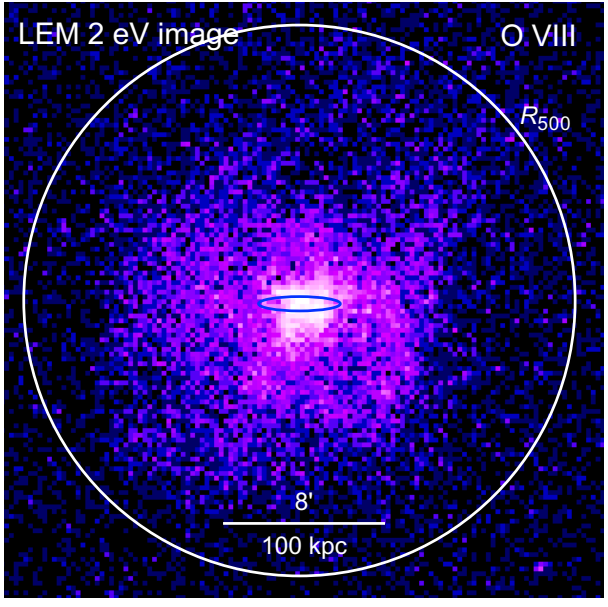
X-ray spectrum of a hot galactic halo

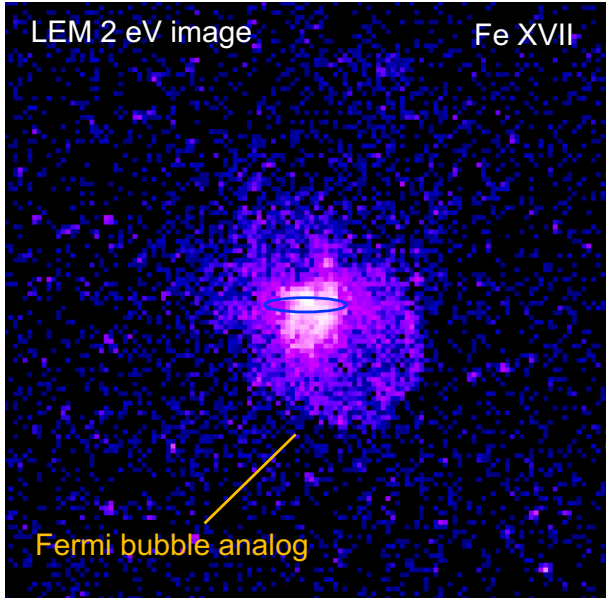


- Signal from galactic halos overwhelmed by the much brighter emission of the Milky Way's own halo
- Need ~eV spectral resolution to disentangle the redshifted halo signal from the MW foreground

How to detect emission from galactic halos?



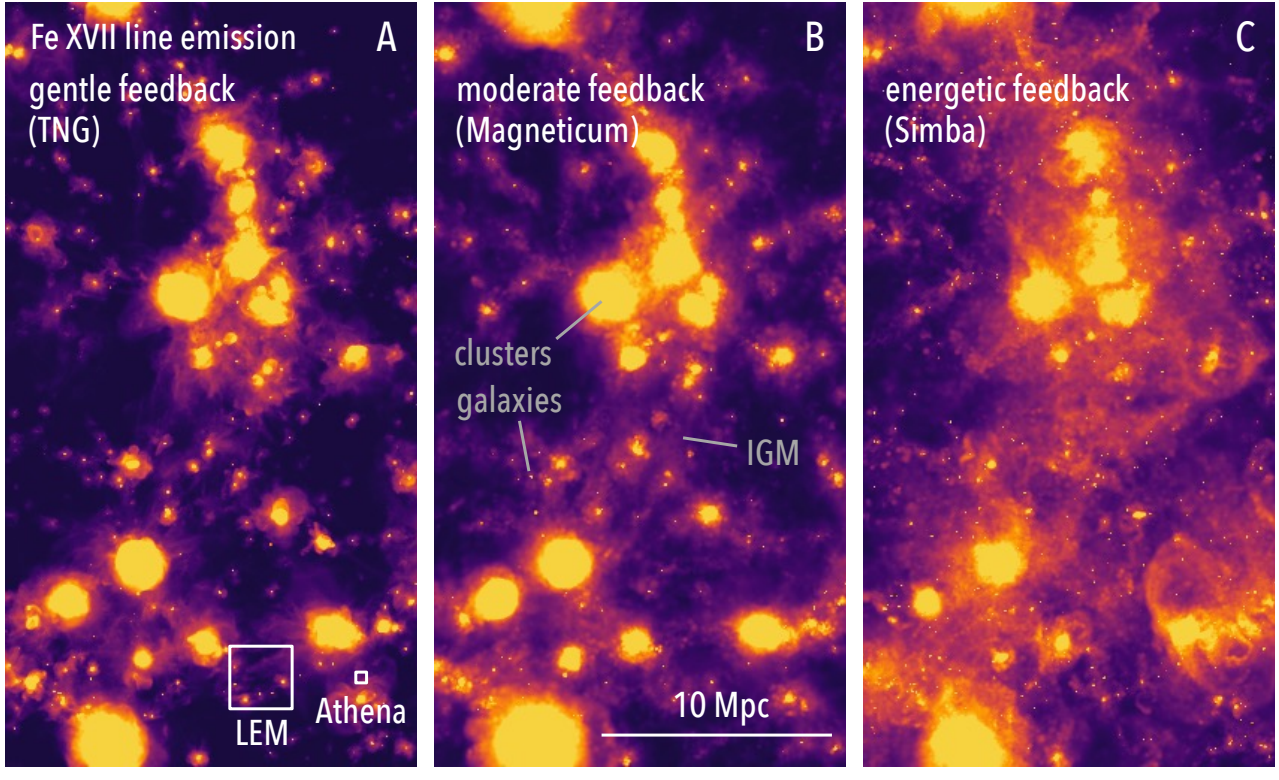




Simulated Milky Way-like galaxy at z=0.01 (LEM 1 Ms exposure)

- Left: CCD resolution (70 eV) image – cannot see the extended halo, because the **MW foreground dominates**
- Middle, right: LEM images in 2 eV energy bins centered on the O VIII and Fe XVII lines. Most of the MW **foreground is removed**, revealing the full extent of the hot halo and the AGN bubbles

Detecting metals in the Cosmic Web



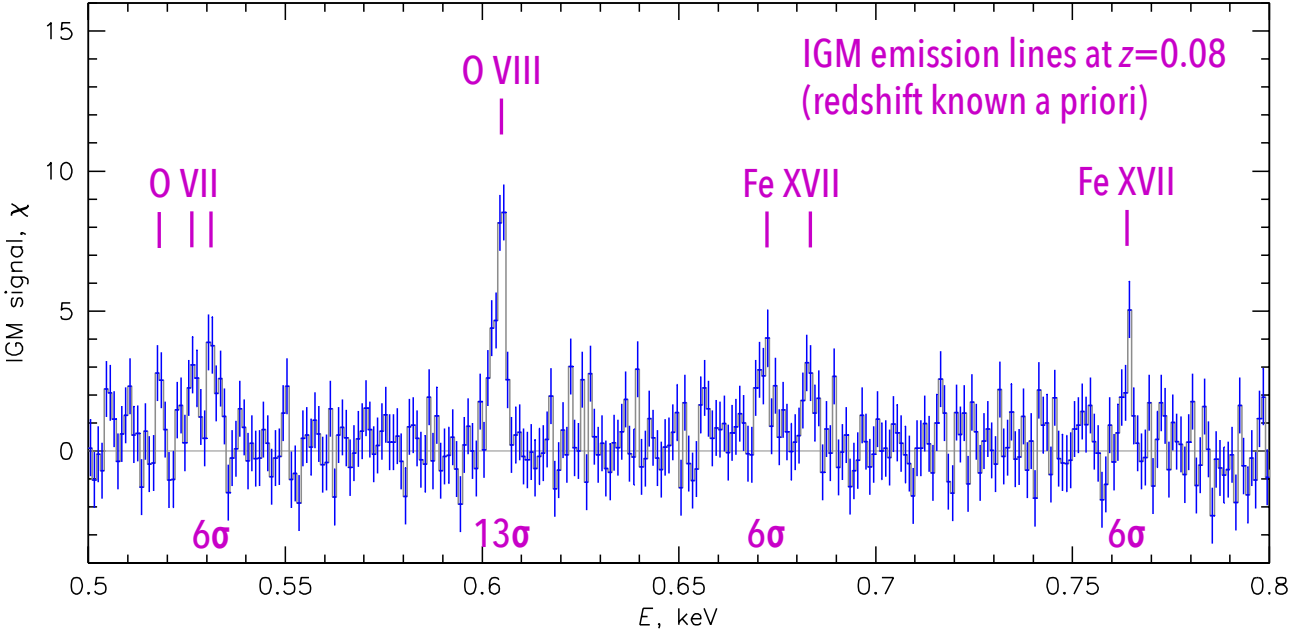
Cosmic Web is the ultimate repository of everything expelled from galaxies

- Metal content constrains models of feedback
- IGM emission is extremely faint, overpowered by MW
  - Need **grasp** to collect photons
  - Need **spectral resolution** to separate IGM signal from MW foreground

Detecting metals in the Cosmic Web

LEM spectrum, 2 Ms on-filament region, model B (moderate feedback)

- filament selected from optical surveys at an optimal redshift



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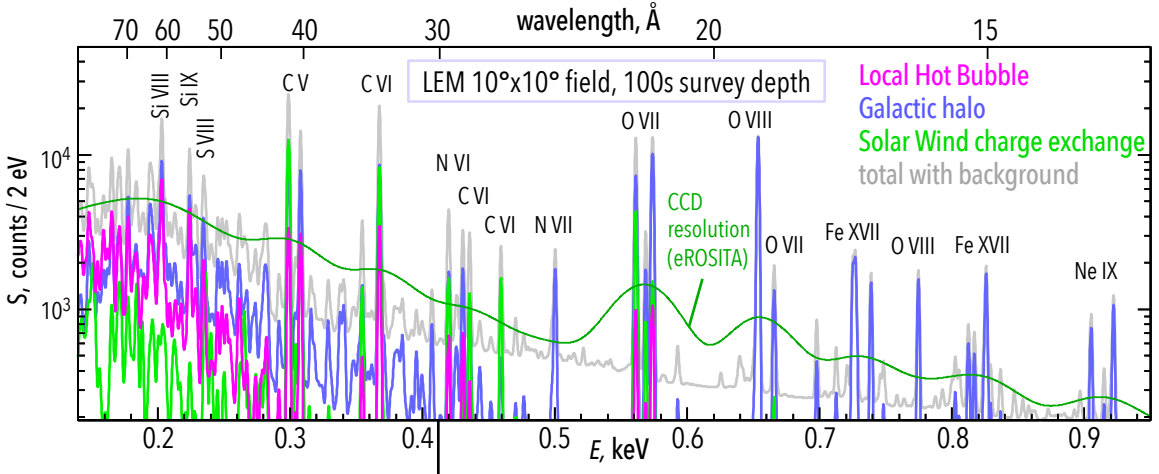
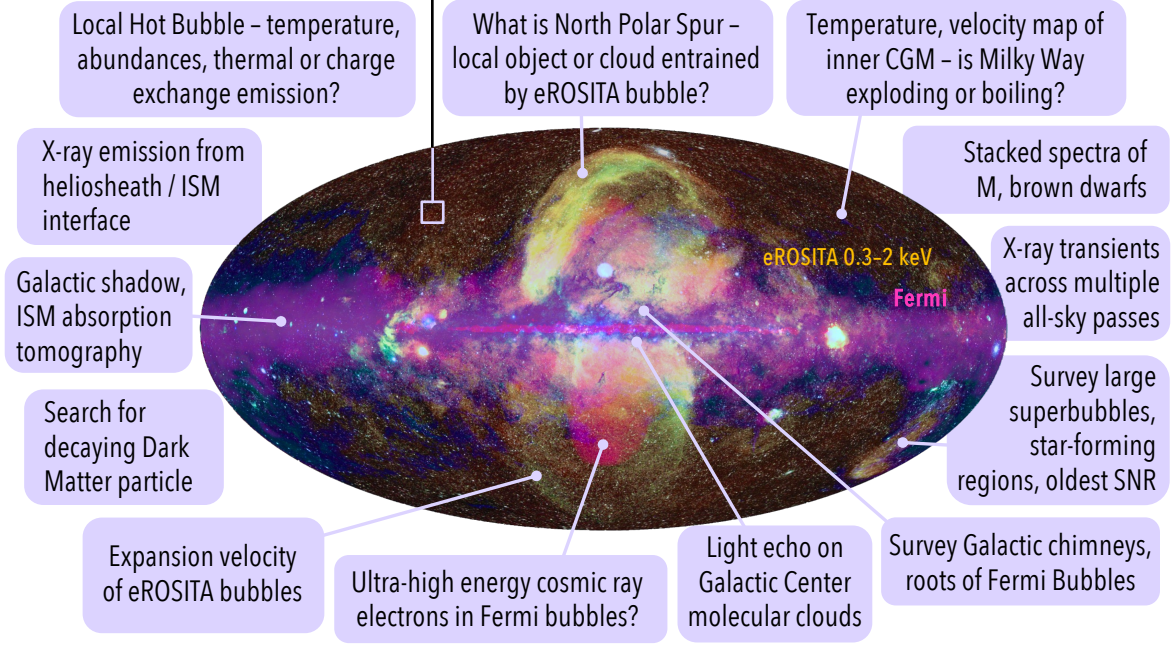
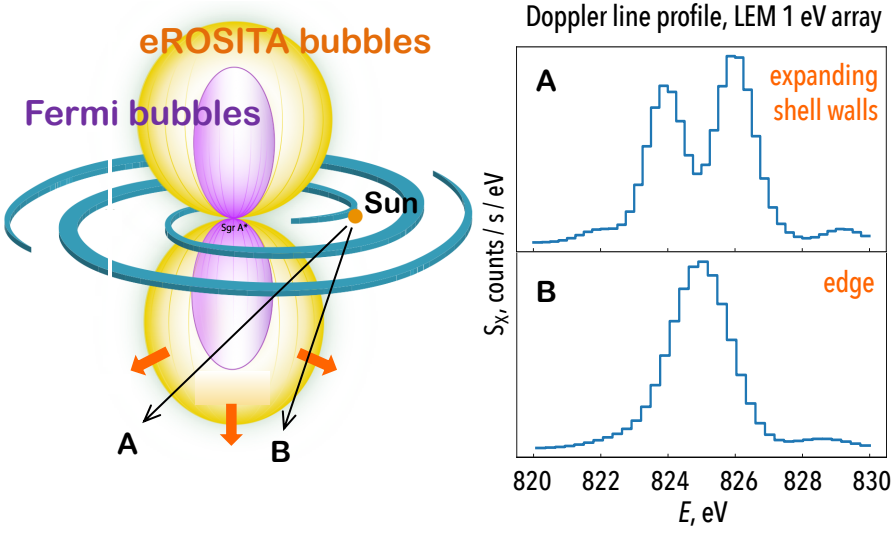
LEM All-Sky Survey

- First survey with 2 eV resolution
- 100s uniform depth (total exposure 16 Ms, only 10% of the mission)
  - **can do because of grasp!**
- Split in ~10 installments (timing studies, SWCX)
- Full, uniform 15” angular resolution
- **inside view on a Milky Way mass galaxy**





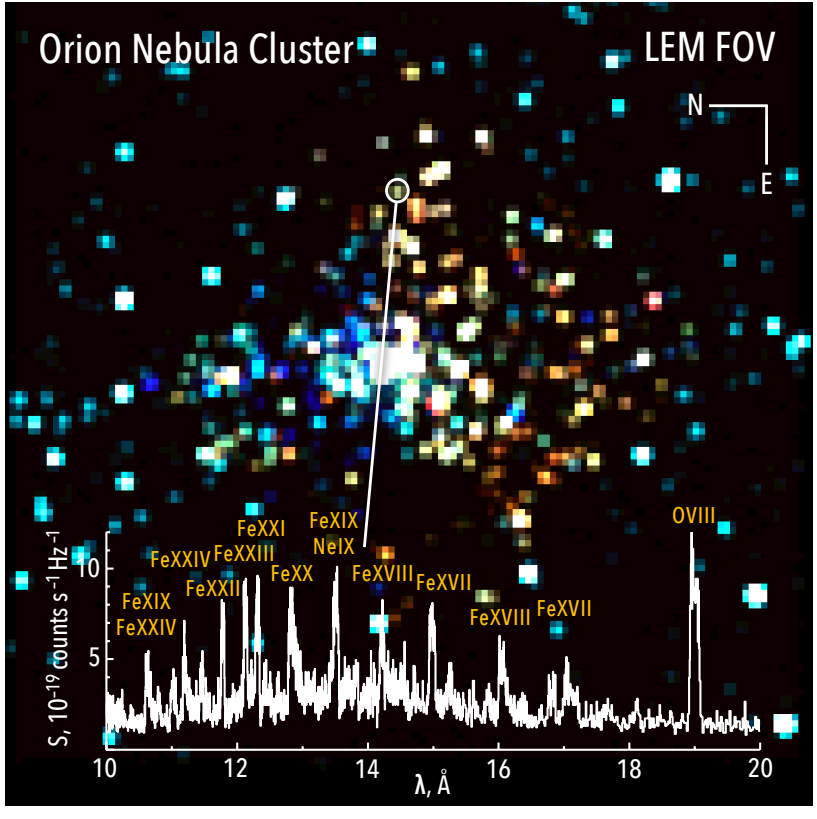
LEM All-Sky Survey



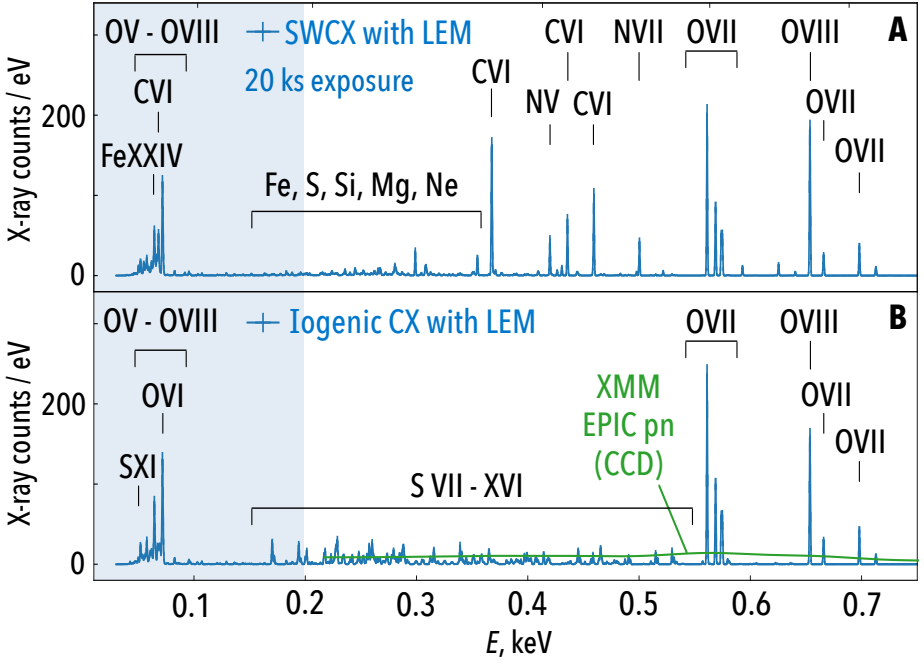
eROSITA bubble expansion velocity:

- use 1 eV inner array (a subset of the survey dataset), E=826 eV Fe line
- can detect ~300 km/s difference between expanding walls of southern bubble for 16x16 deg tiles (15 such tiles cover the bubble)

LEM Guest Observer program – 70% of mission



Jupiter, LEM 20 ks spectrum



- detect z=2-3 galaxy groups and protoclusters
- Earth magnetosphere (SWCX)
- map minerals on the Moon surface
- many more possible studies

Launch date: 2032